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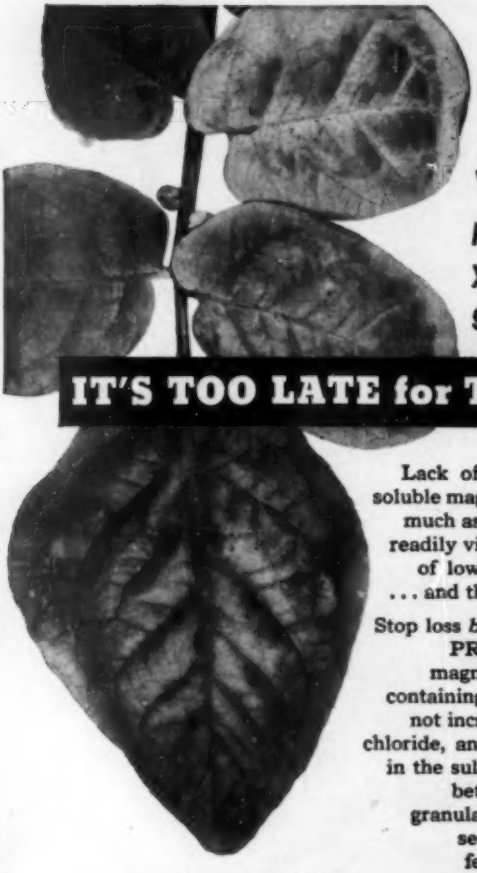

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DORMANCY IN THE POTATO TUBER AND THE EFFECTS OF STORAGE CONDITIONS ON INITIAL SPROUTING AND ON SUBSEQUENT SPROUT GROWTH[1]

T. M. W. Davidson[2]

The importance of the behavior of the potato tuber in storage needs no emphasis whether the ultimate aim be use as ware or seed. Being a living entity the tuber is highly responsive to storage environment which may determine its condition as regards cooking quality, soundness, viability and tuber behavior when planted as seed. With the change to shed and controlled-temperature storage as opposed to older, more primitive, methods, detailed knowledge is required regarding all influencing factors in various combinations and their ultimate effects. With this object in view the following experiments were conducted and observations made of these various storage factors.

In any study of storage the dormancy factor is of prime importance. A widely held view is that the potato tuber has a 'rest period,' that is, a period following harvest when the tuber is incapable of producing sprouts in 'optimal conditions for sprouting,' or in other words, in conditions which are known to bring about sprouting in the shortest possible period of time. In sub-optimal conditions for sprouting the tuber requires a longer period to sprout, and this is called the 'dormancy period.' This is the period of time, including the 'rest period' which the tuber requires to produce sprouts. Emilsson (1) following on the work of others including Wright and Peacock (2), but using storage methods which did not fulfill 'optimal sprouting conditions', found that the potato tuber required from 7-19 weeks 'rest period' depending on the variety used. It will be shown that the potato tuber has no 'rest period' and that the appearance of a readily visible sprout is not a sign of dormancy-break but the first visible indication of growth which has been progressing from the time of harvest.

Growth at the Apical Eye Prior to Minimal Visible Sprouting

Visible sprouting has been regarded as the critical sign of growth-commencement or the end of the dormancy period in the potato tuber. In order to study the possibility of growth proceeding for some time prior to visible sprouting, random samples of ten tubers each, from the same plot of the variety Majestic, were lifted at haulm maturity and stored in two batches at constant temperatures of 80° F and 39° F. Ten tuber samples from each storage environment were examined at intervals and the lengths of the median-longitudinal section of the sprout-initials of the apical eyes were measured using a micrometer eye-piece. Apical eyes were used for this study as apical dominance in tubers is most pronounced early in the storage period. Readings were taken at intervals which appeared to be suitable for the purpose and which fitted in with other work. The mean readings are shown in figure 1.

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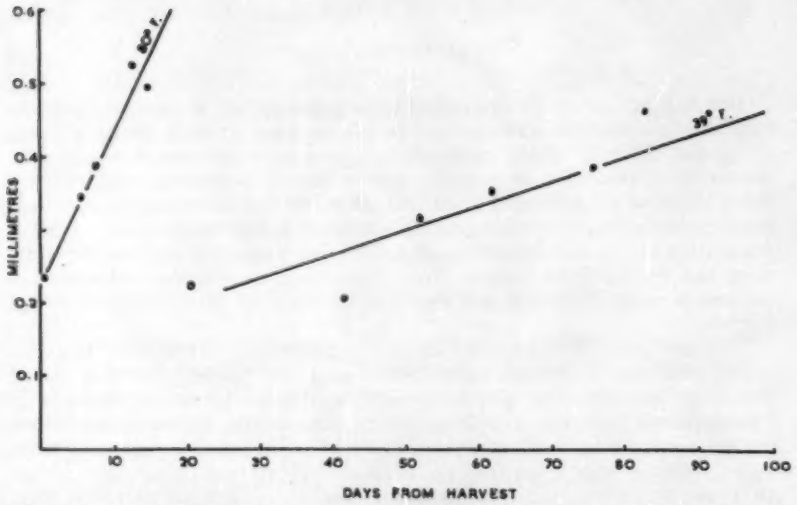

FIGURE 1—Graph showing the growth curves of the apical eye sprout-initials of potato tubers (variety Majestic) from harvest to visible sprouting at two storage temperatures. each point is the mean of a ten tuber sample.

From figure 1 it will be noted that growth proceeds rapidly at the sprout-initials of the tubers stored at 80° F., showing minimal visible sprouting after two weeks in storage. From this, no incapacity for growth is evident. In the same manner growth has been proceeding more slowly at the sprout-initials during storage at 39° F. When the sprout-initial attains the length of .45 mm. it becomes visible to the naked eye as a sprout. As the length of the sprout-initial at harvest is in the region of .2 mm. the increase of .25 mm. occurs within the period of apparent tuber dormancy (Figure 2).

THE EFFECT OF STORAGE CONDITIONS ON THE LENGTH OF THE PERIOD FROM HARVEST TO MINIMAL VISIBLE SPROUTING

In this experiment, fourteen varieties comprising four first earlies, seven maincrop and three late maincrop were used. The stocks were free from virus and other diseases and were grown together in plots of thirty plants per variety. The plots were harvested at haulm-maturity except in the case of the three varieties noted in table 1, which were harvested after the haulms had been killed by frost.

The tubers from each variety after harvest were divided into four equal lots varying from 50-100 tubers and placed under different storage conditions. Reasonably constant temperature chambers were used except in the case of normal shed storage. It was expected that the tubers stored at 68° F ($\pm 5°$ F) would be in optimal conditions for sprouting and those at 80° F ($\pm 5°$ F) in maximal conditions. A cold store at a temperature of 35° F ($\pm 2°$ F) was used to store tubers in minimal conditions for sprouting. The

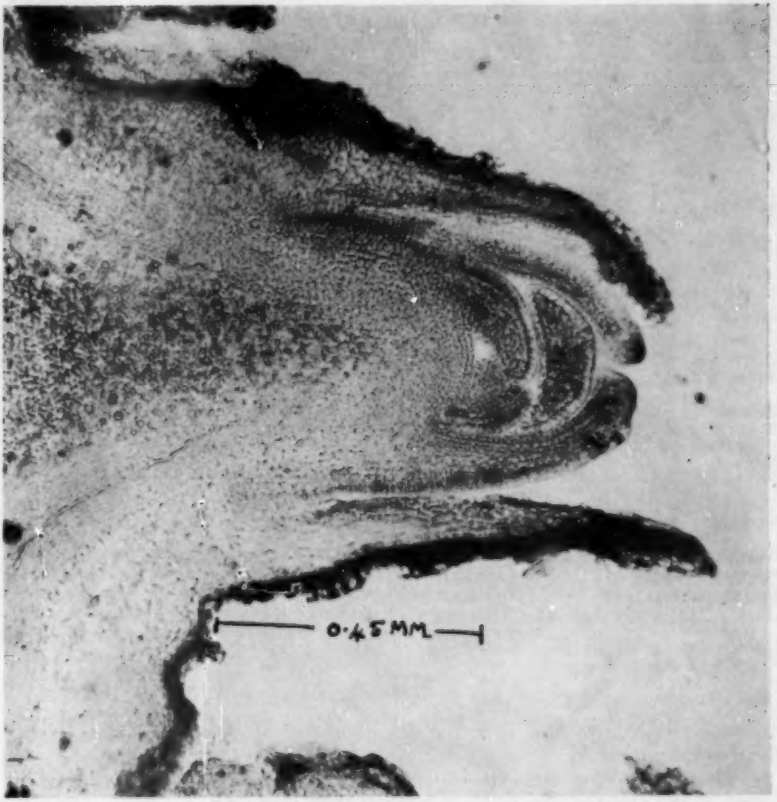

FIGURE 2—An apical *sprout-initial* of a tuber at the point of visible sprouting, .45 mm. in length.

approximate relative humidity is given in table 1 but it will be shown later that humidity and also light have no influence on the length of the period from harvest to minimal visible sprouting at least in the higher range of temperatures.

ENVIRONMENTAL FACTORS AND THEIR EFFECT OF THE LENGTH OF THE STORAGE PERIOD TO MINIMAL VISIBLE SPROUTING

Some account must be given at this point of the effect of environmental factors.

Temperature. The temperature of storage appears to be the primary environmental factor influencing the length of the storage period to minimal visible sprouting. The viability range of sound tubers is from just below freezing point, in the region of 30° F for a few hours to 120° F, also for a few hours. The temperature giving the shortest period of storage to

TABLE 1—*Days from harvest to minimal visible sprouting of tubers in different storage conditions.*

Variety	Maturity	Harvest Date	Average Days to Minimal Visible Sprouting			
			90-95 Humidity Per cent		Normal Storage at Concurrent Air Temps. and Humidity with Heating During Frost	95-100 Humidity Per cent
		1955	80° F.	68° F.		35° F.
Epicure	1st Early	20/8	45 (33)†	64	97 (75)	177 (101)
Ulster Chieftain	1st Early	29/8	46	57	97	136
Home Guard	1st Early	29/8	28	34	..	73
Arran Pilot	1st Early	10/9	39	47	68	82
Record	Early Maincrop	16/9	32	46	87	109
Arran Consul	Early Maincrop	11/10	30	43	135	150
King Edward	Early Maincrop	13/10	28	32	89	141
Orion	Early Maincrop	19/10	31	39	100	138
Dr. McIntosh	Early Maincrop	19/10	13	21	47	87
Majestic	Early Maincrop	19/10	21 (22)	41	89 (80)	136 (120)
Redskin	Early Maincrop	20/10	20	22	69	136
*Kerr's Pink	Late Maincrop	20/10	13	20	45	84
*Golden Wonder	Late Maincrop	20/10	38	39	117	151
*Up to Date	Late Maincrop	20/10	20	22	65	93

†Bracketed figures are for a second year of test.
*Haulms killed by frost.

minimal visible sprouting is in the neighborhood of 80° F and that giving the longest period 35° F or possibly a degree or two lower (Figure 3).

Humidity. The humidity of storage has apparently no effect on the length of the period to visible sprouting at high temperatures (Table 2) but may have some effect at lower temperatures of storage although this is thought to be slight.

Light or Dark Conditions. These conditions have no effect on the length of the period to minimal visible sprouting (Table 2) and it is thought to have no effect at lower temperatures.

INHERENT FACTORS AND THEIR EFFECT ON THE LENGTH OF THE STORAGE PERIOD TO MINIMAL VISIBLE SPROUTING

Variety. Varieties differ one from another in many ways but the behavior within the variety is relatively stable, thus the storage period to visible sprouting for any variety is found to be constant; the higher the storage temperature the narrower are the limits of spread about the mean period of sprouting. From table 1 it will be noted that there is a general correlation between varietal earliness in ripening and a relatively long period from harvest to minimal visible sprouting at the higher storage temperatures. In figure 3, results with two varieties have been plotted to show

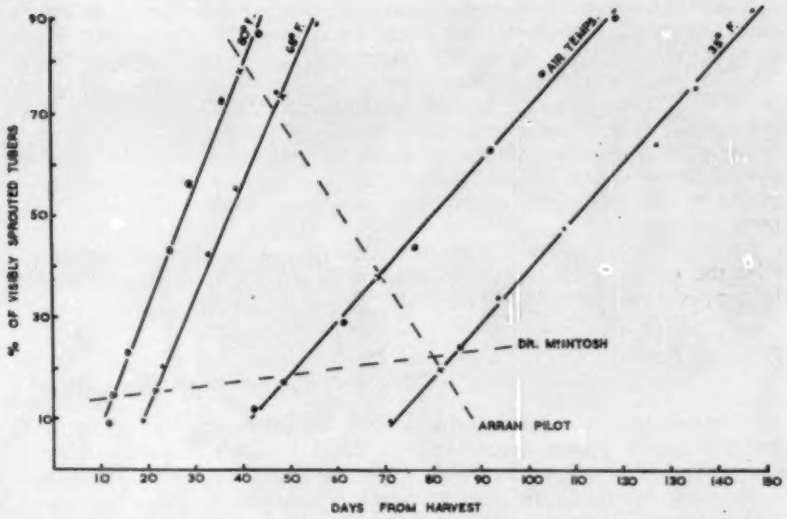

FIGURE 3—Days from harvest to visible minimal sprouting for tubers of fourteen varieties, comprising approximately 1,000 tubers per storage condition. The curve 'Air temperatures' is for shed-stored tubers at concurrent air temperatures above freezing point. The difference between varieties in different storage conditions is shown by the plotted path of two varieties (Arran Pilot and Dr. McIntosh).

TABLE 2—*The effect of humidity and light on the length of the storage period to visible minimal sprouting in storage at 80° F for samples of 250 tubers.*

Storage Conditions	Average Storage Period in Days to Minimal Visible Sprouting		
	Dark Relative humidity 40 Per cent	Light Relative humidity over 90 Per cent	Dark Relative humidity over 90 Per cent
Variety			
Epicure (1st Early)	33	33	33
Majestic (Maincrop)	26	21	22

the difference between varieties in relation to the individual periods of storage required for minimal visible sprouting at different temperatures.

Other inherent factors have been reported in literature as affecting the length of period to visible sprouting namely: Size of tuber (1) (3); degree of tuber maturity (1) (2) (4) (5); starch content (3).

Size of Tuber. This appeared to have no appreciable effect.

Degree of Tuber Maturity. Immature tubers were found to require a longer period of storage to minimal visible sprouting in all storage conditions.

Starch Content. The variety Golden Wonder is relatively rich in starch and it may be observed from table 1 that it was outstanding amongst the late main crop varieties in requiring a longer storage period to minimal visible sprouting in all storage conditions. The effect of variation in the starch content of individual tubers within the variety has not been examined but it is not thought to have any appreciable effect.

Foliage Variants. Tubers of feathery wildings were tested against normal tubers of the variety Majestic but little variation was found in the period of storage to minimal visible sprouting required at all storage temperatures.

Virus Diseases. These were found to have little effect on sprouting with the exception of Virus Y infection which required an appreciably longer period to sprout at 80° F and 35° F than the normal.

Non-environmental Factors and Their Effect on the Length of the Storage Period to Minimal Visible Sprouting

Fungal Diseases. Tubers infected with dry rot *(Fusarium coeruleum)*, severe common Scab (*Streptomyces scabies*) or other organisms have a shorter period of storage to visible sprouting than have the healthy tubers of the same variety at the same storage temperatures.

Wounds. Tuber wounds which heal quickly, such as clean cuts and indentations, have no effect, whereas slow healing or partially healed wounds such as frost damage, is usually accompanied by a certain amount of rot which affects the storage period to minimal visible sprouting in the same was as infection by a fungous disease (Figure 4). It appears that a certain amount of fungous or bacterial rot is associated with the shortening of the period to visible minimal sprouting at temperatures lower than optimal.

Chemical Treatment. Many chemical treatments of tubers can be used to shorten the period of storage to minimal visible sprouting ('dormancy breaking'). The author has found that *Ethylene Chlorhydrin* (5 c.c. per liter, air space) can shorten the period of storage to minimal visible sprouting even under optimum conditions. It is interesting to compare the results given in table 1 with those of Stuart and Milstead (6). Storage at 80° F is apparently almost as efficient a means of 'dormancy breaking' as the use of chemical treatments, but there is no doubt that in the lower and normal range of storage temperatures tubers can be made to sprout more quickly by the use of such chemical treatments.

Work has been conducted to test the effect of oxygen concentration on the breaking of the 'rest period' of tubers, but the clear cut results obtained by Thornton (7) were not substantiated by Sawyer and Smith (8).

Discussion on the Period from Harvest to Minimal Visible Sprouting

Visible sprouting or an arbitrary sprout length has been regarded previously as the critical sign of growth commencement from potato tubers. From the above results it has been found that growth appears to be continuous at the apical eye after harvest (Figure 1) and the growth rate is dependent on the storage temperature alone, light having no effect and

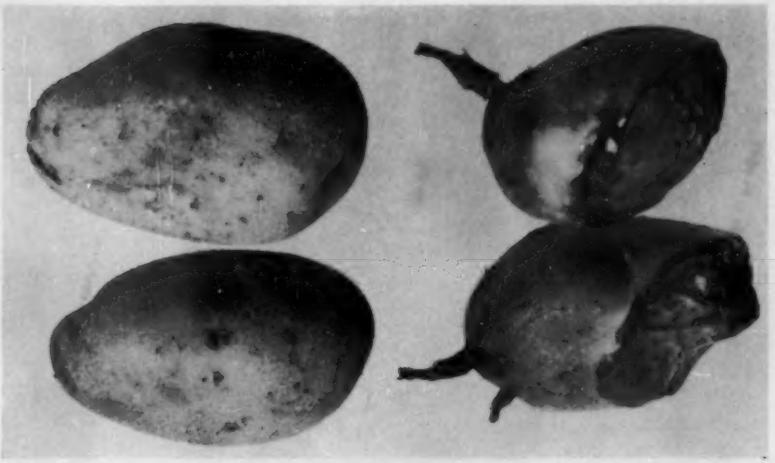

FIGURE 4—Majestic tubers, frost damaged and normal from the same plant, stored in normal shed storage showing the effect of a partially healed wound on the rapidity of visible sprouting and on the consequent growth.

humidity having possibly some slight effect only at low storage temperatures. The growth at the apical eye being dependent upon the temperature, there is no question of dormancy existing in potato tubers but only a natural conditioning for perennation from one season to the next. If the term 'dormancy' implies absence of visible growth then the potato tuber may be dormant for periods of up to five months in conditions sub-optimal for sprouting, but if the term infers incapacity for growth then the potato tuber has no dormant period.

The appearance of a general correlation between varietal earliness of ripening and a relatively long storage period required to visible sprouting at 80° F is interesting. (Table 1). This character may be a necessary factor for earlies which, maturing in the height of the summer should not sprout rapidly in spite of favorable growing conditions existing at and subsequent to harvest. This factor may be due to selection by breeders and growers or possibly by a natural selection of genes, where an early variety in natural conditions would sprout and grow into a young plant to be inevitably destroyed by the first frost of the winter. In storage at 35° F visible sprouting is delayed for nearly 5 months and, as will be shown later, growth thereafter is extremely slow.

THE EFFECT OF STORAGE CONDITIONS ON SUBSEQUENT SPROUT GROWTH AFTER MINIMAL VISIBLE SPROUTING

After minimal visible sprouting occurs, light, humidity and temperature play compensating roles in their various combinations. Of these, temperature is the primary factor, then light, and lastly, humidity.

At high temperatures (80° F) sprout growth is mainly independent of humidity and light. Sprouts appear within a few weeks after harvest (Table 1) and growth is rapid for several weeks by which time the sprouts vary from one-half to an inch in length, thereafter growth slows down and thickening of the sprout occurs, the length at the end of the storage period (March-April) being ¾ to 1 inch. The effect of humidity and light may be judged from figure 5 where high humidity and dark conditions have promoted growth in the latter part of the storage period.

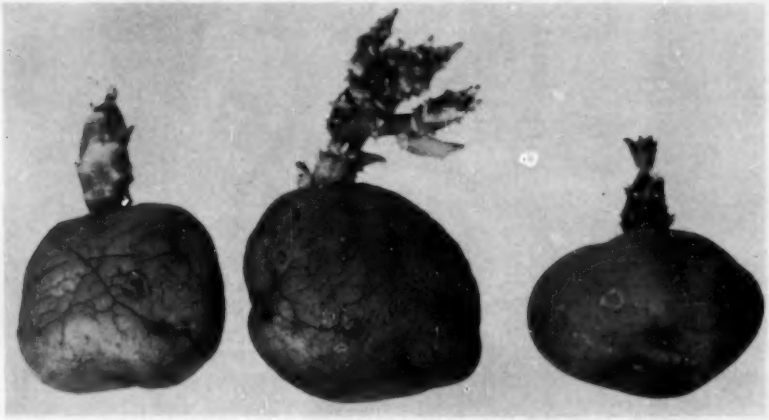

FIGURE 5—Tubers of the variety Epicure after seven months storage at 80° F.
Left: Approximately 40 per cent relative humidity, dark
Center: Approximately 95 per cent relative humidity, dark.
Right: Approximately 95 per cent relative humidity, light.

At room and at winter air temperatures above freezing point access to light is the primary factor in controlling sprout growth. Minimal visible sprouting occurs on the average about 11 weeks after harvest and thereafter the rapidity of growth is dependent on light access, other conditions being equal. This may be observed, in general, by comparing a typical tuber of Redskin after five months storage in boxes in light at normal air temperature (Figure 6 A) and tubers of the variety Dunbar Standard after five months storage at 50° F in the dark (Figure 7).

In low-temperature storage (35° F) minimal visible sprouting takes place, on the average 17 weeks after harvest, and sprout growth thereafter is slow; with light access and humidity having for all practical purposes only a slight effect to the end of the normal storage period.

It will be noted that the Redskin tuber shows minimal visible sprouting after approximately twenty weeks in storage (Figure 6B). At normal planting time in March and April, tubers of all sixteen varieties tested over two seasons were sound, with sprouts of ¼ inch or so in length. Tubers stored at 35° F remained in excellent condition for longer periods than those normally required. All tubers remained sound and sprout growth was very slow. (Figure 8).

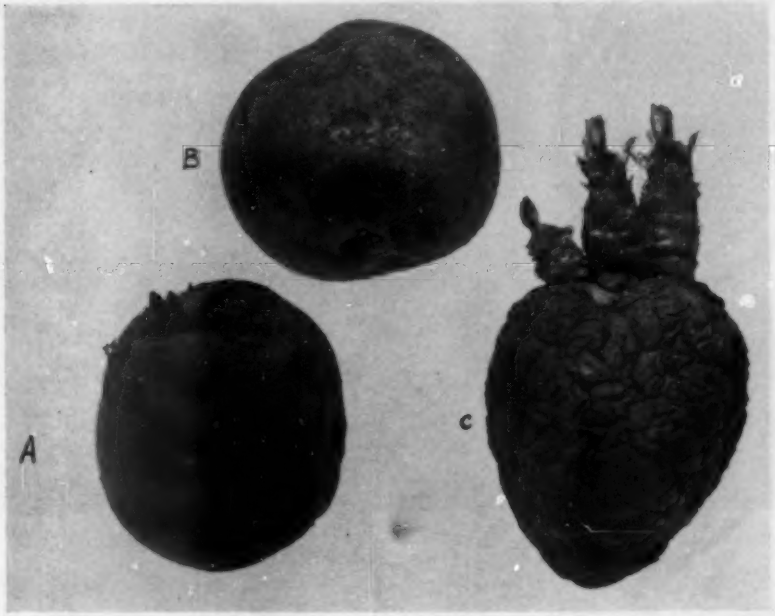

FIGURE 6—Tubers of the variety Redskin stored for 5 months at
A. Air temperatures above 32° F. in light
B. 35° F., dark; and
C. 80° F., dark

DISCUSSION. To keep the sprout growth of stored tubers to a minimum is the aim of all growers whether the ultimate use be ware or seed. It is equally important from the point of view of 'seed' exporters where long distances and hot conditions are involved. There is no doubt that cool storage at constant temperatures varying from 35-38° F are ideal for storage and transport, giving a sound end product with very little sprouting. Samples cooked along with controls showed the quality of tubers from cool storage to be unaffected, when boiled. Flesh color is intensified during cool storage and flavor becomes more apparent. In tubers destined for chipping, storage at temperatures above 40° F is advocated by Smith (9), but without inhibitors sprouting under these conditions would be excessive as all tubers for consumption must be kept in the dark. Tubers for 'seed' can be kept in excellent condition at normal room air temperatures provided there is good access of light. A graph of the combined effects on sprouting of temperature and light is shown in figure 9. Humidity plays only a minor role in increasing the rapidity of sprout growth.

FIGURE 7—Tubers of the variety Dunbar Standard after 5 months storage at a constant temperature of 50° F., (±5° F.) in the dark.

THE EFFECT OF STORAGE ON SUBSEQUENT DEVELOPMENT OF THE POTATO

To observe the after effects of storage on field performance, tubers from the three varieties King Edward, Golden Wonder and Arran Consul, from three storage treatments, were planted in nine separate random blocks. The tubers were planted at a double spacing of three feet between plants to allow for sample liftings during the growing season and to obviate the effect of removing plants upon the remainder. Five plants of each variety from each storage condition were harvested at fortnightly intervals after tuberization and their yields recorded (Table 3).

Plots of five varieties were also planted from tubers stored in the same storage conditions as the above and were used for general observation and pilot yield trials (Table 4).

TABLE 3—*Yields of fifteen plant samples, five per variety of three maincrop varieties; King Edward, Golden Wonder and Arran Consul.*

Storage Treatment	Weeks from Planting							
	11	13	15	17	19	21	23	25
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
80° F.	4	17	31	52	59	70	75	81
Air Temperaure	½	8	25	49	66	73	75	80
35° F.	..	3	24	40	57	64	73	73

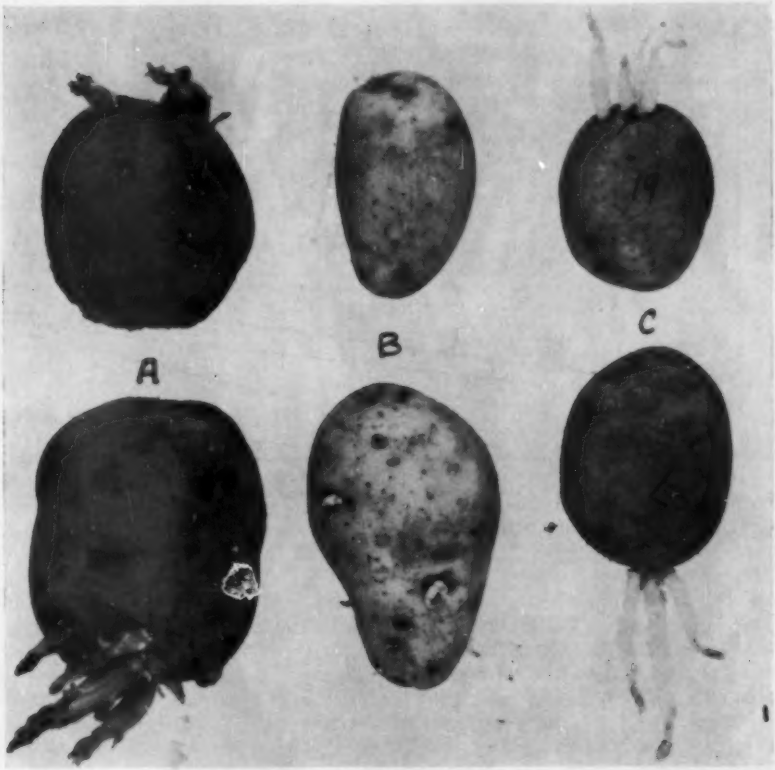

FIGURE 8—A. Epicure tubers after eleven months; B. Majestic and C. Dunbar Standard tubers after 10 months at 35° F. in the dark.

DISCUSSION

Although the scope of the above experiments is limited the effect of storage on yield has since been confirmed by statistical experiment. With all the varieties grown, plants from tubers stored at 80° F emerged on the average fourteen days before those tubers which were shed-stored at concurrent air temperatures above freezing point. The latter emerged on the average eight days before these stored at 35° F. The difference in vigor was obvious between the three treatments until almost mid-season, eleven weeks after planting. In the early varieties where maturity of the haulm was unimpeded by frost, the warmer the storage the earlier was the maturity (Table 4). The term maturity is used as meaning the point at which maximum yield is obtained and is judged by the yellowing of the senescent haulm. From table 3 it will be noted that the warmer the storage the earlier tuberization

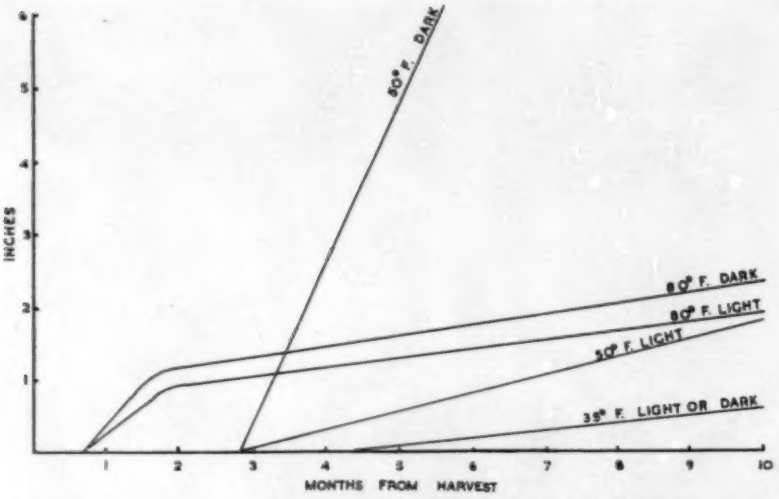

FIGURE 9—Graph of the combined effects of temperature and light on the rapidity of sprout growth.

takes place and in those varieties that reached maturity unimpeded (Table 4) the warmer the storage the lower was the final yield. So, from the practical point of view, cool-stored tubers, although later in emerging and in tuber forming, eventually catch up, and, in the case of varieties unimpeded by frost, out yield warmer-stored tubers at maturity. Where earliness of cropping is important fairly warm storage (45-50° F) in boxes with good light access might be advantageous.

OTHER FEATURES

The incidence of the spread of rot diseases in cool storage has not been studied specifically but there is evidence that cool-stored tubers are less able to seal-off inoculated material of the gangrene fungi *(Phoma foveata* and *P. tuberosa)* than those tubers stored at a higher temperature although infection of tubers dipped in a spore suspension was much less at the lower temperature in the presence of moisture. (10). In the tests reported here which covered three seasons the tubers were kept in boxes in a cool store at a constant temperature of 35° F where they remained sound and free from rots. A feature of warm storage is the incidence of 'little potato,' a physiological condition where the life cycle is contracted, as evidenced by the production of young tubers on the sprouts of the old 'set' (Figure 10B). The condition may be induced artificially by transferring sprouted tubers from warm to cold storage (Figure 11). From experiments carried out by the author warm storage alone will not produce 'little potato,' three factors being involved *viz.*, 1, warm storage; 2, proliferated sprouting due to injury

TABLE 4—*Pilot yield trial of the effect of storage temperature on subsequent maturity and yield.*

Variety	Storage Treatment					
	80° F.		Normal Shed Storage at Concurrent Air Temperatures with Heating During Frost		35° F.	
	Yield†	Date of Maturity	Yield†	Date of Maturity	Yield†	Date of Maturity
	Lbs.		Lbs.		Lbs.	
Arran Pilot 1st Early	69	11/8	84	15/8	96	26/8
Record (Early)	57	15/8	83	28/8	89	10/9
Majestic (Maincrop)	105	14/9	127	20/9	125	*
Orion (Maincrop)	111	18/9	137	*	126	*
Kerr's Pink (Maincrop)	112	*	114	*	116	*
Up to Date (Maincrop)	135	*	122	*	123	*

†Yield figures are for 27 tubers planted.
*Not matured when the haulms were killed by frost September 21st, 1956.

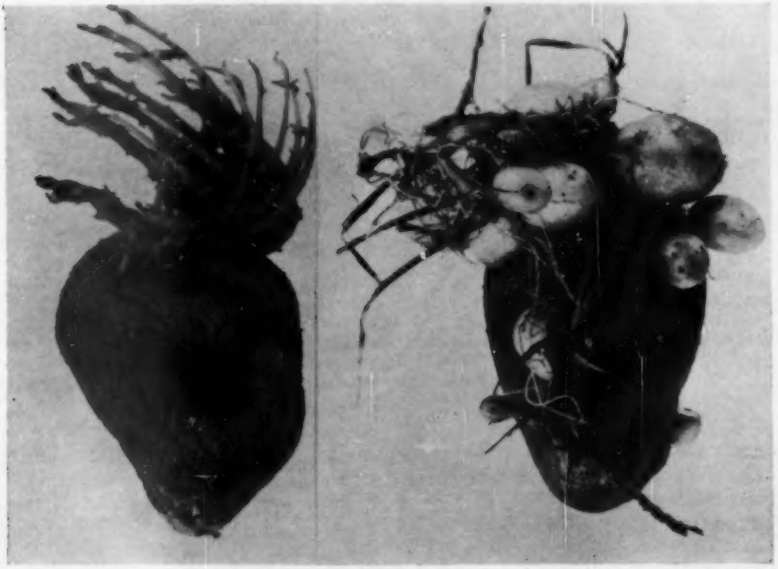

FIGURE 10—A. Tuber of the variety Dr. McIntosh stored at 80° F. showing sprout proliferation caused by damage to the apical sprout. B. The same tuber some weeks after planting, the weather conditions having been cool.

FIGURE 11—A tuber of the variety Epicure transferred from storage at 80° F. to storage at 35° F. in March. (Photographed in June.)

of any form to the apical sprout or sprouts, and 3, a cool period after planting. The condition may be permanent, as shown in figure 10B, but all degrees of severity may be found in the field as a result of variation of the influencing factors.

CONCLUSIONS

1. Sprout growth is continuous at the apical eye of potato tubers after harvest. There is no incapacity for growth, but this growth is not visible to

the naked eye as a sprout for a period of time, depending on the storage conditions.

2. Temperature is the prime factor in controlling the length of the period from harvest to minimal visible sprouting; humidity may have some effect in the lower temperature range but light has no effect.

3. Cool storage at 35-40° F is ideal from the point of view of the soundness of the end product and minimum sprout growth. Where tubers are stored for seed purposes at higher temperatures light access is essential to prevent etiolation.

4. In general, the warmer the storage conditions the earlier is tuberization and maturity with a lower final yield than cooler-stored tubers.

Acknowledgment

My thanks are due to the Director of the Scientific Services of the Department of Agriculture for Scotland for his help and for facilities granted to me, to Mr. Muir Laidlaw for the photographs and to Dr. Alexander Nelson of the Royal Botanic Garden, Edinburgh.

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INCREASING PREVALENCE OF INTERNAL BLACK SPOT OF POTATOES ON THE NEW YORK CITY MARKET.

B. A. FRIEDMAN AND S. M. RINGEL[1]

In studies reported in 1945 from this laboratory (3), the prevalence of internal black spot in Long Island-grown Green Mountain potatoes was noted. In that report no mention was made that the disorder was seen in potatoes received on the New York City market from other growing areas. In 1950-1951, however, internal black spot was reported from a number of eastern states as well as some western states (2,4). During 1956 samples were received at New York from inspectors who reported finding about 25 per cent internal black spot in two carload lots of Washington State-grown Russet Burbank potatoes. In 1957, the association of potassium nutrition and internal black spot was observed in Russet Burbank tubers in California (1), and a marked increase of this disorder in British Columbia was reported (5).

Scattered observations made during the last several years at this laboratory have made it evident that internal black spot has become increasingly important in potatoes shipped from many producing areas to eastern terminal markets. For example, although California-grown White Rose tubers have been examined in test shipments at this laboratory for years, internal black spot has seldom been observed. During the summer of 1957, seven lots of these potatoes were examined. At arrival at the New York City market, internal black spot ranged from 4 to 24 per cent, with an average of 16.9 per cent (Table 1). It was observed that the internal black spot occurring in the California-grown potatoes was almost entirely restricted to the stem-ends of the tubers. In eastern potatoes, however, internal black spot has been observed to be scattered over the entire tuber surface. Although internal black spot has, in the past, been found largely in potatoes from storage, recent observations indicate its prevalence in freshly harvested potatoes as well.

In view of the apparent increase in internal black spot, measures to control this disorder should be undertaken if high potato quality is to be maintained on the market.

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[1]Accepted for publication, November 22, 1957.

[2]Senior Plant Pathologist and Plant Pathologist, respectively. Market Pathology Laboratory, Agricultural Marketing Service, United States Department of Agriculture, New York, N. Y.

TABLE 1—*Incidence and severity of internal black spot in California-grown White Rose potatoes.*

Lot[1]	Tubers Examined	Internal Black Spot		
		Slight[2]	Damaged[2]	Total
	No.	Per cent	Per cent	Per cent
1	256	..	..	24
2	74	4	0	4
3	74	8	1	9
4	81	10	6	16
5	78	15	5	20
6	80	15	5	20
7	73	6	1	7
Total	716			
Average				16.9[3]

[1]The severity of internal black spot was not recorded for lot 1; lots 2 to 7 were taken from 6 different carlot loads sent in test shipments from California to New York by U.S.D.A. personnel.

[2]Slight internal black spot was not considered to be of commercial significance; damaged tubers were considered to have 5 per cent or more waste and to be scorable against grade.

[3]Average determined on basis of total affected tubers and total number of potatoes examined.

SOME EFFECTS OF RESTRICTED SOIL AERATION ON POTATOES[1]

H. W. GAUSMAN, K. F. NEILSEN, AND R. A. STRUCHTEMEYER[2]

Soil conditions resulting from various management practices are known to affect the composition of the soil atmosphere. As indicated by Russell (5), it is usually assumed that plant growth will be affected by these varying conditions, although quantitative verification is often lacking. Irrigation and compaction seem to be two of the main factors which limit gaseous diffusion with a resultant high CO_2 to O_2 ratio in the soil atmosphere.

Unfortunately, very little literature exists in regard to effects of differential soil O_2 and CO_2 on potatoes. In addition, it is questionable whether results from investigations concerning other plant genera would apply, since it may be surmised that a potato plant may be more responsive to variations in soil atmospheric content because of the development of a large and concentrated supply of subterranean carbohydrates. Nevertheless, some of the more recent results with plants other than potatoes will be cited.

In a comprehensive study on tobacco by Harris and van Bavel (2,3), it was indicated that plant functions are not greatly reduced until the CO_2 concentration becomes greater than the O_2 concentration in the soil atmosphere. Further, nutrient uptake was relatively unaffected at O_2 concentrations above 10 per cent, although a concentration of 5 per cent CO_2 seemed to stimulate phosphorus uptake. In this respect, Shapiro *et al* (6) found a significant phosphorus-oxygen interaction in applying a diffusion equilibrium technique to corn, but there was very little potassium-oxygen interaction. Earlier work by Lawton (4), however, indicated that a large amount of potassium fertilizer would offset the affects of poor soil aeration, since it was found that the absorption of potassium by corn plants was more dependent on soil aeration than the uptake of nitrogen, magnesium, calcium, or phosphorus.

Results reported herein are from experiments designed to evaluate the supposition that the effects of low O_2 levels on potatoes may be reduced by increased potassium concentration. To fulfill this objective, the interaction of various fertilizer treatments with restricted aeration has been investigated.

MATERIALS AND METHODS

Investigations were conducted during 1955, 1956, and 1957 with a virgin Caribou loam soil in pot culture (1 gal.). Fertilizer treatments in pounds per acre of N — P_2O_5 — K_2O were: 300-0-400, 300-250-400, 300-400-400, 300-250-250, 300-400-250, and 300-400-0. Nitrogen was supplied from $(NH_4)_2SO_4$ + $(NH_4)_2HPO_4$, phosphorus from $(NH_4)_2HPO_4$, and potassium from KCl. Dolomitic limestone was added to each pot at a rate of 4,000 pounds per acre. The Kennebec variety of potato served as the indicator plant, and seed pieces were treated with PCNB (pentachloronitrobenzene). Gypsum moisture blocks were imbedded in the soil to aid in

[1]Accepted for publication, November 27, 1957.

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maintaining moisture content of the soil above 50 per cent field capacity. Following an adapted procedure of Shapiro *et al* (6), an inverted funnel imbedded in the soil over glass wool was connected to a gas-collection chamber. Seed pieces were planted above and slightly to one side of the inverted funnel. Watering tubes were also imbedded in the soil. Carbon-dioxide concentrations were estimated with a Model CND, Fyrite CO_2 Indicator.[3] A Beckman Model D Oxygen Analyzer was used to estimate the O_2 concentration.[4]

Statistical methods as given by Snedecor (7) were followed in the analyses of data.

Variation in experimental procedure between years was mainly caused by experimental design and to changes in the methods of sealing pots. In 1955 a split-plot Latin square was used. Randomized block designs were used in 1956 and 1957 with four and three replications, respectively. In addition, Krillium was added to each pot in 1955 at a rate of 2,000 pounds per acre to afford a better control of differences in soil structure.

Pots were surface-sealed in 1955 with a mixture of 5/16 Petrolatum, 5/16 beeswax, 5/16 paraffin, and 1/16 lanolin (6). All pots received either a heavy or a very light application of the wax. It was deemed necessary to use a light application to give some control of the possible effects of the wax mixture on plant growth. Some difficulty was encountered because of the expansion and contraction of the wax mixture, and for this reason a rubber covering was used in 1956. Low-melting point paraffin was used in 1957 and resealed as necessary.

Results and Discussions

Results for 1956 are not included in this paper. In that year all pots were sealed due to the primary objective of investigating alterations in root morphology which have previously been reported (1).

Considerable variation was encountered between the O_2 and CO_2 readings for 1955 and 1957. A variation of 0.5 to 6.0 per cent CO_2 occurred in pots when aeration was restricted, and a range of 0.25 to 0.75 per cent was usually obtained when the aeration was not restricted. Oxygen readings ranged from 18.3 to 21.5 per cent, 21.5 per cent being the approximate value for plants with unrestricted aeration.

CO_2 Measurement

Table 1 depicts CO_2 readings from the 1955 experiments. Although considerable variation is evident between treatments, variation within treatments was surprisingly constant. This would seemingly indicate that the various fertilizer treatments affected the measurable amount of CO_2 differently. Lending some support to this is the fact that the replication mean squares were not statistically significant. Tukey's test of all comparisons among treatment means (7) indicated that the CO_2 readings for the 300-0-400 treatment differed significantly from the 300-250-250 and 300-250-400 treatments. Results were indicative of a higher CO_2 value when phos-

[3]Bacharach Industrial Instrument Company, 7301 Penn Avenue, Pittsburgh 8, Pa.
[4]Arnold O. Beckman, Inc., 1020 Mission St., South Pasadena, Cal.

TABLE 1—*Carbon-dioxide measurements from 1955 experiment, average of 6 replications.*

Treatment	Restricted	Unrestricted	Difference between Restricted and Unrestricted[2]	Mean of Restricted and Unrestricted[3]
	CO_2 Per cent	CO_2 Per cent	CO_2 Per cent	CO_2 Per cent
300-0-400	1.80	0.59	+1.21	1.20
300-250-400	0.93	0.47	+0.46	0.70
300-400-400	1.70	0.13	+1.57	0.92
300-250-250	1.20	0.14	+1.06	0.67
300-400-250	1.40	0.14	+1.26	0.77
300-400-0	1.80	0.23	+1.57	1.02
Mean[1]	1.47	0.28		0.88

L. S. D.'s 5 per cent level
[1]Restricted vs. unrestricted=0.16
[2]Treatment with restricted vs. unrestricted=0.39
[3]Treatment means=0.28

phorus was lacking. Using Tukey's test for the interaction of treatment with restricted aeration *vs.* unrestricted aeration, (7), the 300-250-400 treatment differed significantly from the 300-400-0, 300-400-250, and 300-400-400 treatments. The 300-250-400 treatment tended to give consistently lower CO_2 readings when aeration was restricted than with all the other treatments. No explanation can be given other than the possibility that an interacting effect was present on some respiratory mechanism of the plant or non-obligate anaerobic organisms.

EFFECT ON PLANT HEIGHT

In 1955, height measurements were taken on three dates; August 25, September 9, and September 19. As indicated by results shown in table 2, fertilizer treatments in combination with both restricted aeration and unrestricted aeration significantly affected plant height. As noted previously, the 300-400-400 fertilizer was responsible for the greatest height with both restricted and unrestricted aeration, and, according to Tukey's test, it differed significantly when compared with all remaining treatments. Of special interest is the indicated interaction of restricted aeration *vs.* unrestricted aeration with fertilizer treatments as affecting plant height. It is worthy of note that the 300-400-250 treatment was the only treatment which resulted in a greater plant height with restricted aeration than when aeration was unrestricted. Other notable differences also occurred with the following comparisons: 1) 300-400-400 *vs.* 300-0-400 gave a difference of 0.55 inch in height in favor of unrestricted aeration, 2) 300-400-400 vs. 300-400-0 resulted in a 0.61 inch height differential favoring unrestricted aeration, 3) a comparison of 300-400-250, 300-250-250, and 300-250-400 indicates that 400 pounds per acre of P_2O_5 with 250 pounds per acre of K_2O was more effective in alleviating the effects of restricted aeration than 250 pounds per acre of P_2O_5 with 400 pounds per acre of K_2O.

TABLE 2—*Effects of restricted and unrestricted aeration on height of potato plants (1955 experiment, average of 6 replications).*

Treatment	Unrestricted	Restricted	Difference in Height between Unrestricted and Restricted	Mean of Unrestricted and Restricted[2]
	Inches	Inches	Inches	Inches
300-0-400	18.06	16.36	+1.70	17.21
300-250-400	18.67	17.67	+1.00	18.17
300-400-400	20.92	18.67	+2.25	19.80
300-250-250	18.22	17.89	+0.33	18.06
300-400-250	17.64	18.56	−0.92	18.10
300-400-0	17.56	15.92	+1.64	16.74
Mean[1]	18.51	17.51		18.01

L. S. D.'s 5 per cent level
[1]Unrestricted vs. restricted=0.80
[2]Treatment=1.39

Results in 1956 (data not included) were in accord with those of 1955. According to Hartley's sequential method of comparing means (7), fertilizer treatments consisting of 300-400-400, 300-250-250, and 300-400-250 differed significantly and positively from the 300-250-400 treatment. In addition, the 300-250-250 treatment gave a statistically significant earlier increase in plant height as determined by four height measurements during the growing period.

EFFECTS ON DRY MATTER YIELD

Effects of restricted aeration and unrestricted aeration on total dry matter yield are denoted in table 3 for 1955 and 1957. In essence, results are quite comparable with those of plant height. Highest total dry matter yield resulted with the 300-400-400 fertilizer treatment when aeration was not restricted, but again the 300-400-250 treatment gave the highest total dry matter yield when aeration was restricted. Considering a break-down of the data for the 300-400-250 fertilizer treatment into dry matter production for tops, roots, and tubers (data not included), restricted aeration resulted in an increase in dry matter production. This amounted to an 8.6 per cent increase for tops, 14.7 per cent increase for roots, and 33.5 per cent increase for tubers.

Although critical percentages of CO_2 and O_2 were not utilized, results on height measurements and dry matter production are indicative of an interaction of phosphorus with restricted aeration and unrestricted aeration. Results suggest that additional phosphorus might alleviate some effects on the growth of potato plants when edaphical, environmental and managerial factors are conducive to poor soil aeration. These results tend to support the findings of Shapiro *et al* (6) in that they reported a significant phosphorus-oxygen interaction but little potassium-oxygen interaction in applying a diffusion equilibrium technique to corn.

TABLE 3—*Effect of restricted aeration and unrestricted aeration on total dry matter yield of potato plants.*

Treatment	1955[1]		1957[2]		Mean	
	A.R.*	A.N.R.*	A.R.	A.N.R.	A.R.	A.N.R.
Pounds per Acre	Grams	Grams	Grams	Grams	Grams	Grams
300-0-400	5.97	6.39	15.50	20.00	10.74	13.20
300-250-400	10.69	8.54	18.50	18.00	14.60	13.27
300-400-400	10.76	12.99	16.00	21.00	13.38	17.00
300-250-250	11.88	10.10	20.00	19.00	15.94	14.55
300-400-250	13.02	9.52	23.00	15.00	18.01	12.26
300-400-0	11.09	12.34	12.00	11.00	11.55	11.67

L. S. D.'s 5 per cent level
[1]1955=0.71 for treatment
[2]1957=2.23 for treatment
A.R.*=Aeration restricted
A.N.R.*=Aeration unrestricted

SUMMARY

Results of pot experiments with potatoes conducted over a 3-year period concerning restriction of aeration by surface sealing indicate that phosphorus has a mitigating effect as evaluated by plant height and dry matter production.

It is suggested that additional phosphorus might improve potato production when edaphical, environmental and managerial factors are conducive to sub-normal soil aeration.

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TEST SHIPMENT ACROSS U. S. PROVES POLYETHYLENE TO BE IDEAL POTATO PACKAGE

A test which involved shipping potatoes across the nation has proven polyethylene to be an ideal container for the vegetable, able to withstand long haul shipments.

The Shellmar-Betner Flexible Packaging Division of Continental Can Company in conjunction with the U. S. Department of Agriculture, the S. A. Camp Company (shipper), the Kern County (California) Potato Growers Association, Atlantic & Pacific Tea Co., and the Bakelite Company, conducted a test providing for shipment from Cawelo, California to New York City, of a number of California Long White Rose potatoes packed in both regular paper mesh window bags and 10# polyethylene bags.

Results of the experiment overwhelmingly favored the polyethylene packages for the following reasons:

Weight loss in transit for polyethylene-bagged potatoes was reduced to 10 per cent of the weight loss of those bagged in paper.

Weight loss in storage (after receipt) was ⅓ to ½ less in polyethylene-bagged potatoes.

Polyethylene-bagged potatoes were of firm texture and good quality, while potatoes in paper containers were shriveled and spongy to the touch.

Because of dehydration, potatoes in paper bags became severely discolored—no discoloration was noted in polyethylene-bagged potatoes.

No flavor differences were reported between the potatoes packaged in polyethylene and those in paper; however, housewives preferred the potatoes in polyethylene bags because they were firmer and easier to peel.

DIAL-SET PRINTER DEVELOPED

"Down Maine", the State Department of Agriculture has found an efficient way to imprint tags for Certified Seed Potato bags. During the busy potato season, hand stamping of variable information on the certification tags could not keep up with requirements for tags. With 26 varieties of Certified Seed Potatoes and over 1500 different growers, a better way was needed to put these names (as well as date and inspector's name) on the certification tags.

The Maine Department of Agriculture rented eight Model-D Dial-Set printers from Dennison Manufacturing Company, Framingham, Mass. As a grower prepares to bag his Certified Seed Potatoes, he orders the necessary number of tags from the Department of Agriculture. The local state inspector imprints these on the Dial-Set printer.

The Dial-Set machine permits the setting of all copy by merely turning a dial—and no proofreading of individual tags is required. With automatic counter control, any specified number of tags may be imprinted at a speed of 165 impressions per minute. A neater tag and more efficient system has been the result.

The pre-numbering on the tags permits State Accounting to record the sale of tags and the growers to whom certification tags have been sold. The growers attach the tags to the filled potato bags by threading the jute that closes the bag top through the hole in the tag patch.

RESULTS OF 1957 FUNGICIDE TESTS PUBLISHED

The American Phytopathological Society for several years has sponsored the publication of results from tests on newer fungicides. The "Results of 1957 Fungicide Tests" for the first time has been printed privately and is isued as a single copy. This replaces the previous practice of combining reprints of serial articles published in "Agricultural Chemicals." The "Results of 1957 Fungicide Tests" can be secured at $1.00 per copy only from Dr. A. B. Groves, Department of Plant Pathology and Physiology, Winchester Fruit Research Laboratory, Rural Route 3, Winchester, Virginia. All orders should be accompanied by remittances made out to The American Phytopathological Society. An added charge will be made for postage and handling where orders must be billed.

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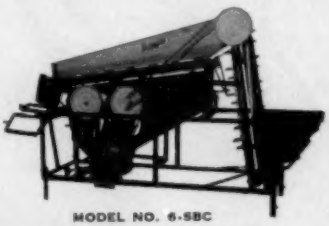

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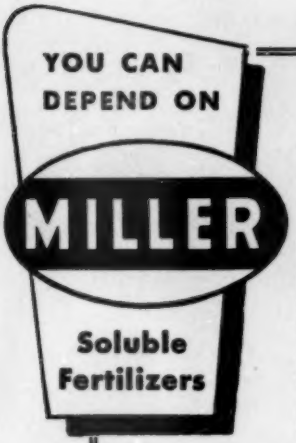

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Thoroughly tested copper-zinc-chromate complex that has provided excellent results for growers and in agricultural experimental stations.

Controls diseases on POTATOES, TOMATOES, CUCURBITS, PEANUTS, CITRUS, AVOCADOS, AZALEAS and TURF

Supplies needed Trace Elements — improves vegetable quality

Safe to use . . . no residue tolerance restrictions on harvested crops

Sticks better as spray or dust

Economical . . . does not break down in storage

Available to Research Workers

NUTRI-LEAF "60" Soluble Fertilizer

Safe, easy nourishment for plants. Feeds quickly . . . can be mixed with insecticides and fungicides. 20-20-20 analysis with trace elements and a sticker-spreader. Also a hormone added to increase root growth and promote setting. Available to Research Workers.

40% TEPP INSECTICIDE (KILLMITE 40)

The most potent phosphate insecticide widely used against a great variety of insects. Can be safely used without dangerous residue to crops within 72 hours of harvest.

- Kills mites that are resistant to other phosphates
- Provides outstanding control of aphid, cabbage worms, etc.

TOMATO-SET HORMONE SPRAY

Increases the set, fruit size and yields of early tomatoes. Can be applied with your regular insecticide and fungicide programs.

- First tomato hormone that can be applied as ***overall spray***
- Insures good crop during period when weather is unfavorable for fruit setting. Spray when blossoms are opening.
- Effectiveness demonstrated by three years of research work.

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the fungicide potato growers trust for early and late blight control

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